Flare star investigation – two decades of cooperative observational study in Budapest and Byurakan

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In 1969, when I got acquainted with the questions of flare phenomena, the investigation of these eruptive stars was over on the early stages of research. The first known flare star, DH Carinae, was discovered by E. Hertzsprung in 1924. Hertzsprung took plates for finding variable stars in the region of Carina and a flare of 1.8 magnitude was observed. Hertzsprung (1924) wrote in his note: "After the outburst, which took place on the third plate, the star lost about a magnitude in brightness in the course of about 1.3 hours." This observation had been forgotten and only after the discovery of the UV Ceti was it brought to the center of attention. It is interesting that Hertzsprung tried to consider a mechanism which could explain the phenomenon: "A rough estimate indicates that a fall into the star of a body like a small planet would yield sufficient energy for an outburst as observed..."

In the following 15 years a whole range of authors reported on accidentally observed flare events. For example, in the Orion nebula several stars showing similar changes of brightness have also been discovered. Among the numerous reports on extremely sudden increase in the brightness of some stars Wachmann's (1939) article was the first note on a flare event observed spectroscopically.

The star is now designated as V371 Ori. The lines of Balmer series were seen during the flare and the first small part of the trailed spectrogram was very intense followed with an abrupt drop in the spectroscopic continuum during the last part of the spectra (Wachmann, 1939).

Many of the flare stars were discovered during observations aimed at finding high proper motion stars. So the existing early data on the accidentally discovered flare stars are of a heterogeneous origin. The first observed flare stars were large proper motions objects in the vicinity of the Sun. They are low luminosity dwarf stars with spectral types of M0 or later and they have emission lines mainly of H and CaII during the normal state. The similarity of the observed features led van Maanen (1945) first to the idea that these stars may belong to the same class.

The field of flare star research really took off with the discovery of flares on Luyten 7268. The star had been known for its high proper motion and on 7 December 1948, E.F. Carpenter in Tucson made a multiple exposure plate for parallax purposes (see

Luyten, 1949). There are five consecutive exposures on the plate, each exposure took 4 minutes, while the total observation lasted about 20 minutes. The rapid increase in brightness of about two magnitudes, followed by a decrease of the same amount and all this happened in a 20 minute interval. From this moment it was clear that a new and until then unknown form of the brightness variation had happened and a new type of variable stars had been discovered. Today, the star is known as UV Ceti, the prototype of the flare stars. I have to mention, that three months earlier, even in September, Joy & Humason (1949) recorded the spectrum of UV Ceti during an eruptive change of brightness.

Also, as a class, the flare stars have spectral types of late M through late K, corresponding to the effective temperatures between about 2500 to 4000 K. They often have detectable emission lines of hydrogen and calcium in their spectra, indicating chromospheric activity. They have masses between 0.1 and 0.6 solar masses. Variability in the flare stars is characterized by rapid, irregular, large amplitude increases in stellar brightness, followed by a much slower decay (from minutes to hours) back to a quiescent level. Before the abrupt changes, a smooth light enhancement occurs in the continuum brightness. After this the really flare up takes only several seconds. The first part of the decay is also steep but slower than the brightening, which is followed by a longer lasting, quasi exponential part. The strongest variations occur in the blue and in the UV range: a flare may cause a one magnitude change in the V band, but more magnitudes in the U band. And during the flare event the star makes a loop on the colour-colour diagram. From the spectroscopic point of view, flares are typically accompanied by brightening of the emission line spectra of the star, particularly of the Balmer series of hydrogen, and the appearance of ionized helium lines as well. Flares have also been observed in the radio and X-ray regions of the spectrum, though they are not necessarily coincident with optical flares.

In 1945 Alfred Joy published a pioneering paper that initiated the study of emission-line stars associated with nebulosity. Ambartsumian (1947) showed that the bright-line variables are concentrated in certain regions where the star density is ten to one hundred times larger than in the neighbouring stellar fields. From this evident clustering of these objects Ambartsumian concluded that these stars had a definite genetic relationship and perhaps a common origin. Ambartsumian called these regions T-associations.

In 1953 Haro and Morgan reported on three rapid variables discovered in the Orion nebula. In rapid succession flare stars were found in other stellar aggregates and clusters of different ages – for example in NGC 2264, Pleiades, Coma, Praesepe, and Hyades clusters.

These flare stars in stellar aggregates radically changed the earlier picture based on the UV Ceti variables in the solar vicinity. Flares have been observed not only in Me dwarfs but also in stars of spectral type as early as K0, or earlier, and the absolute luminosities of these stars during quiescence correspond to cool subgiants as well as to dwarfs.

The *great flare hunting* started at the end of the 1960s. It was begun by Haro and his collaborators in Tonantzintla, and followed at Asiago – by Rosino –, in Byurakan – by a whole group of observers –, and in Budapest. The most intense observing campaign took place at the Byurakan observatory.

The Byurakan Astrophysical Observatory was founded in 1946 on Victor Ambartsumian's initiative. He became the first director of the observatory, and the main direction of astrophysical investigations – observational and theoretical aspects of stellar evolution – was determined by him. The scientific results came just after the foundation of the Byurakan Observatory. New type stellar systems, the stellar associations were discovered.

It was proved that stars are formed by groups. During 15 years intense observing campaign (until 1980) with wide-angle telescopes at the observatories Tonantzintla, Asiago, Byurakan, and Budapest for about 4000 hours of effective time of photographic observations nearly one thousand flare stars were discovered in several stellar aggregates of different ages. My contribution to this observational study was the comparative analysis of Pleiades and Praesepe clusters with about 400 hours effective exposure time, between 1971 and 1980. Photographic methods are usually unsuitable for photometric and colorimetric investigations of rapid variables. Nevertheless, a great number of flare events had been observed by this method. On the one hand, the multi-exposure plates taken with wide-field cameras are excellent means to discover that a change of brightness has taken place but it is not possible to determine the real amplitude of the flare event nor the correct light curve. On the other hand, the data obtained by the photographic method can be used excellently *for statistical investigations.*

Ambartsumian (1969) published the results of first statistical study based on the data of the first 60 Pleiades flare stars published by Haro. Suppose that the sequence of flares of any flare star is of the type of Poissonian stationary process with some mean frequency of occurrence, ν. Then it can be shown that the expected value, n_k of the number of stars that have flared k times during the total duration of observations, follows the relation:

$$n_k = \frac{n_{k+1}^2}{2n_{k+2}}$$

According to the definition, n_0 is the expectation of the number of flare stars that have not flared during the whole time of observation. In fact, it is the number of stars that are not yet discovered. Therefore adding this n_0 to the sum $n_1 + n_2 + ...$ of all stars observed in flares (this is the number of discovered flare stars), we can obtain the total number, N of flare stars in the given stellar aggregate:

$$N = \sum_0^\infty n_k$$

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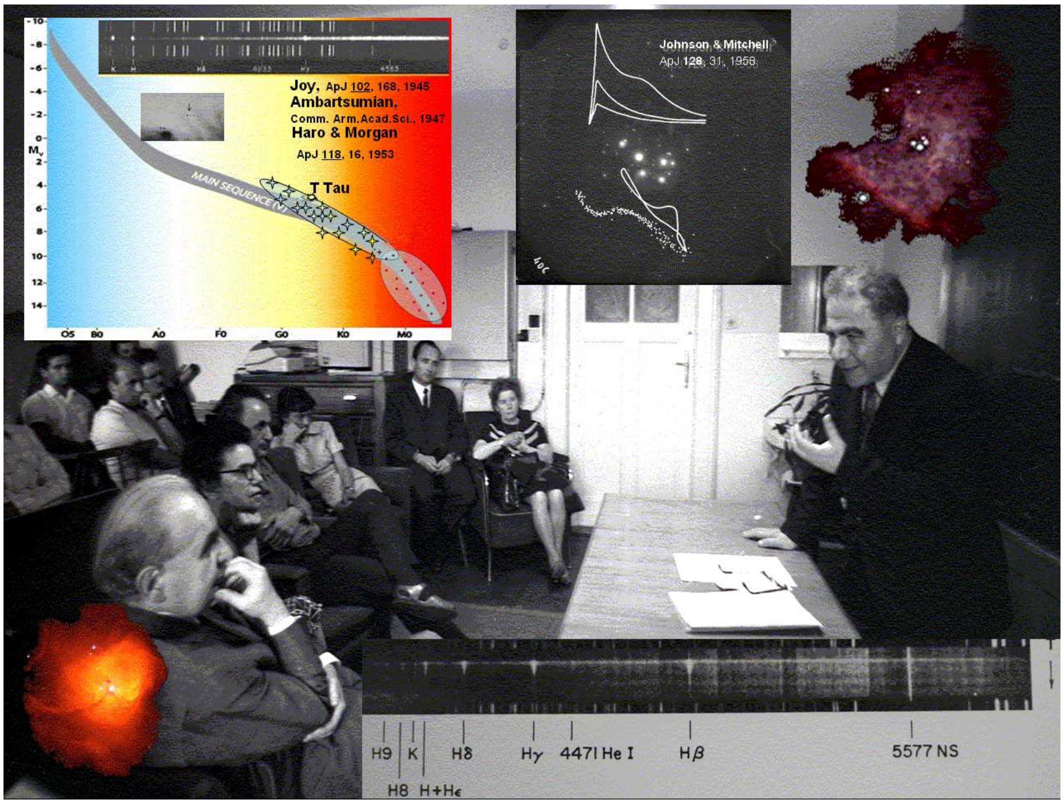

Figure 1: Ambartsumian's lecture for the staff of the Konkoly Observatory in 1969.